USE OF SATELLITE TELEMETRY TO ESTIMATE POST-HOOKING BEHAVIOR AND MORTALITY OF LOGGERHEAD SEA TURTLES IN THE PELAGIC LONGLINE FISHERY IN THE AZORES

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This document represents the final report for Order Number 40JJNF900114. The analyses in this report are preliminary because transmitters are still functioning and data collection is not complete. Conclusions may change as additional data are collected and analyzed.

Background:

It is now well recognized that incidental capture in longline fisheries is a significant threat to sea turtle populations in both the Atlantic and Pacific Oceans (Balazs and Pooley 1994, Balazs et al. 1995, Bolten et al. 1994, Williams et al. 1996). Recovery of US loggerhead sea turtle (*Caretta caretta*) populations is threatened by takes in the longline fishery in the eastern Atlantic. Sea turtle recovery in the Pacific is threatened by longline fisheries there, in which the US/Hawaii based fishery is a small component. However, the US can provide leadership for both Atlantic and Pacific fisheries by estimating loggerhead mortality from these fisheries and working with the industry to develop fishing methods that reduce sea turtle by-catch.

Molecular markers based on mtDNA sequences were recently used to estimate that 90% of the juvenile loggerhead sea turtles in pelagic habitats of the eastern Atlantic (Azores and Madeira) are derived from nesting populations in the southeast US (Bolten et al. 1998). This eastern Atlantic loggerhead population has a range of carapace lengths from 8 - 65 cm (mean carapace length of 35 cm; Bjorndal et al. 2000, Bolten et al. 1993). The duration of the pelagic stage is 6-12 years (Bjorndal et al. 2000). Turtles in this pelagic population are caught as by-catch in the swordfish (*Xiphias gladius*) longline fishery in the Azores, and the largest size classes of loggerheads present in the eastern Atlantic (42 - 65 cm) are impacted by this fishery (Bolten et al. 1994). Increased mortality in this size class of sub-adults has a major demographic effect on loggerhead populations (Crouse et al. 1987).

Behavioral studies, using satellite telemetry, of loggerheads caught on longlines are being used to estimate mortality from hooking. Preliminary studies conducted in 1994 and 1995 have shown the success of using satellite transmitters on juvenile, pelagic loggerheads (Bolten et al. 1996) and suggest that satellite telemetry may be the most cost-effective method to determine mortality.

The focus of a workshop held in Hawaii in November 1993 and sponsored by the National Marine Fisheries Service was to develop a research plan to assess the impacts of hooking from longline fisheries (Balazs and Pooley 1994). The use of biotelemetry to study the behavior and survivorship of hooked sea turtles was identified as a major research priority.

This project was conducted in the eastern Atlantic in the waters around the Azores, using the pelagic-stage loggerhead population as a model. This is an excellent population to use for this study because the population has been well studied (Bjorndal et al. 2000, Bolten et al. 1993, 1998); the impact of longline fisheries on this population has been identified (Bolten et al. 1994); and the reliability of catching turtles has been demonstrated from several years of field work. Another advantage of working with this population is that genetic analyses have shown that the pelagic-stage loggerheads in the eastern Atlantic are part of the US nesting population (Bolten et al. 1998).

Objectives:

- Conduct a study to assess the behavior and movement patterns of pelagic-stage loggerheads caught in a longline fishery
- Determine the feasibility of using satellite telemetry to evaluate survivorship of released turtles caught in a longline fishery

Methods:

Ten pelagic juvenile loggerheads were instrumented with Wildlife Computers (Redmond, Washington) satellite-linked time-depth recorders (SDR-T10 – eight with two C-cell batteries and two with special rectangular batteries) during summer 2000 (Table 1). The first four of these turtles were captured using dipnets, and the other six were captured with commercial pelagic longline fishing gear. The six turtles captured by commercial longline fisheries were hooked in the esophagus. The hook was not removed, and the monofilament line was cut at the wire leader.

The transmitters were attached to the carapaces of the turtles using a silicone elastomer base, fiberglass strips, and polyester resin as described by Balazs et al. (1996). Turtles were typically released within 2-4 days of capture.

All of the transmitters were programmed using Wildlife Computers software version 3.14k. Each transmitter was programmed according to identical parameters to facilitate comparisons (Table 2). The data were received via the ARGOS satellite and data distribution system, and processed using SATPAK software (Wildlife Computers) and the IDL programming language (Research Systems, Boulder, Colorado). All analyses presented in this paper were performed using data from the ARGOS monthly data files.

The position with the best location code from each turtle on each transmission day was used to map the movements of individual turtles. The tracks were also layered with a bathymetry image to determine whether movements show any gross correlations with bathymetry. All maps were produced using ArcView GIS 3.2 (ESRI, Seattle, Washington).

In addition to location information, transmitters also collected information on diving behavior. Turtles had to descend at least two meters for a dive event to register. This decreases the number of wash-overs counted as dives. Dive-profile data are received as six-hour composite histograms of the maximum depth attained on each dive, the duration of each dive, dive counts (derived from the previous two histograms), and proportional time at depth. The histogram periods were designated as follows (local time):

period 0: 21:00 - 03:00

period 1: 03:00 - 09:00

period 2: 09:00 - 15:00

period 3: 15:00 - 21:00

We examined the dive data to identify temporal cycles in maximum dive depth and dive duration. The data from the control turtles from release through 31 October 2000 were used to identify seasonal cycles. We pooled the data from the control turtles in October 1998 (5 turtles) and October 2000 (2 turtles) to identify diurnal cycles in dive behavior and for an exploratory comparison of the behavior of hooked and control turtles. We compared the mean-maximum dive depth and mean dive duration between hooked and unhooked turtles (2000 field season turtles only), on a histogram-period-by-histogram-period basis. Further comparisons will be conducted when the full data sets from hooked and control turtles have been collected. The final analyses will also incorporate the data from another group of control turtles (n = 8) that were instrumented with satellite-linked time-depth recorders (SLTDR's) in summer 2000.

Results:

As of 31 October 2000, two of four transmitters on control turtles and five of six transmitters on hooked turtles continued to function (Figure 1). Battery voltage was still reasonably high (5.8 – 6.7 V) for all functioning transmitters, and transmitter clock drift (+ 0.5 to + 3.1 min) was not sufficient to affect data collection or alter transmission success.

The four control turtles were released simultaneously on 15 July 2000. The tracks of these four turtles are shown in figure 2a. Two of the turtles (22273 and 22209) held very similar courses for the first week. Unfortunately, transmitter 22273 ceased functioning at that time. The tracks of the 6 hooked turtles are shown in figure 2b. The hooked turtles showed similar movement patterns and directions, and most appear to be moving towards the Canaries and Madeira. The movements of all turtles with respect to bathymetry are shown in figure 3. We have not yet quantitatively analyzed whether movements or behavior correlate with bathymetry; statistical analyses will be conducted at the end of data collection when transmitters no longer are functioning.

Visual inspection of the change in mean-maximum dive depth with time suggests a seasonal effect on dive behavior (Figure 4:a-b), with mean-maximum dive depth increasing in the fall. A diurnal pattern in dive behavior is evident for most hooked and unhooked turtles, with the shallowest dives occurring during periods 0 (21:00 – 03:00, Figure 4:a-b, Figure 5:a-b). The distributions of dives for hooked turtle dives are skewed toward longer dives (Figure 6:a-b) and shallower dives (Figure 5:a-b). Unlike controls, they tend to make the longest dives during period 0 (Figure 6:a-b). Hooked turtles also do not show the bimodal distributions of maximum dive depths that is characteristic of control turtles (Figure 5:a-b). Turtle 22208 does not demonstrate a diurnal or seasonal pattern and may be dead (Figure 4:c). After an initial period of weak activity, 22208 ceased to move deeper than 2-5 meters, and these shallow 'dives' may represent wave wash-overs and/or rough seas rather than diving activity. The path of turtle 22208 does not appear different than the movements of other hooked turtles released at approximately the same time (Figure 2b).

Since there is an apparent diurnal pattern to dive behavior, dive statistics for October were calculated on a period-by-period basis for each turtle (Table 3:a-d). Based on dive histogram data from all months, the maximum dive duration (excluding turtle 22208) was between 120 and 180 minutes. Ten dives fell within this range, and all occurred in late October. Turtle 22272 made 7 of these dives and turtle 25312 made 3 of them. Based on the 1-meter resolution maximum depth information obtained from the status messages, the deepest dive was 138 meters, by turtle 22275 in mid-August.

Conclusions:

- Dive behavior of hooked and control turtles appears to have a diurnal component, with the shallowest dives occurring during histogram period 0 (21:00 – 03:00). Dive behavior also has a seasonal component, and dive depth increased for most turtles from summer into fall.
- The diving activity of turtle 22208 is what might be expected from a dead, floating turtle buffeted by waves. These data demonstrate that SLTDR's can function as effective tools for monitoring the post-capture condition of free-ranging sea turtles. In the case of

22208, position data alone would have been insufficient to evaluate condition, since the movements of 22208 were not noticeably different from other hooked turtles.

- In all periods, the hooked turtles appear to make longer and shallower dives than control turtles. These comparisons between hooked and unhooked loggerheads must be interpreted with caution. As stated previously, transmitters are still functioning and conclusive analyses cannot be conducted until all data have been collected.
- High rates of non-mortality related transmitter failure could preclude the use of transmitter failure as an indicator of turtle mortality. Dive profiles are necessary to determine whether transmitter failure is due to mortality or mechanical causes.

Recommendations:

- Satellite telemetry shows excellent promise for the evaluation of the behavior of post-hooked sea turtles from a longline fishery. We strongly recommend the continued use of satellite transmitters that provide dive profiles to assess behavioral differences between normal and hooked turtles. Location-only transmitters will not provide sufficient data to allow for analyses of behavioral changes following hooking.
- Telemetry studies would benefit by evaluation of the causes of premature (pre-battery drainage) transmitter failure in this and other studies. If the causes of failure were more adequately understood, longer time series of data could be collected, and transmitter failure could be used as an indicator of turtle mortality. Data sharing of attachment, diagnostic (manufacturer, battery voltages, # of transmissions, etc.), and transmitter duration information, along with the testing of standard and innovative attachment techniques, will facilitate these advances.

- In some situations it might be appropriate to set the shallowest depth to be considered a dive (see Table 2) to a value greater than 2 meters. This might reduce noise in the dive data by filtering out apparent diving events that are in reality caused by wave action.
- Analyses would be enhanced by the collection of dive profiles from an entire year to document seasonal changes in dive behavior. For the current group of turtles, battery life is the limiting factor on the functional life of the transmitter. To extend the battery life and extend the period of data collection, the satellite transmission duty cycle can be changed from the current 1-day-on / 1-day-off pattern to a less frequent cycle of transmission, e.g., 1-day-on / 5-days-off.
- The interpretation of both movements and dive behavior can be greatly enhanced by integrating this information with environmental data derived from remote-sensing imagery and other oceanographic data sources.

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Table 1. Juvenile loggerhead turtles (*Caretta caretta*) instrumented with satellite transmitters in the Azores Islands – Summer, 2000. Esoph = esophagus.

Transmitter Number	Hooked? Where?	Tag-RF	SCLn-n (cm)	CCL (cm)	SCW (cm)	PL (cm)	Mass (kg)	Date of Release	Release Latitude (N)	Release Longitude (W)
22273	No	BP6755	46.5	52.1	40.2	36.5	17.8	17-Jul-00	38.5	28.8
22274	No	BP6775	42.5	50.0	38.5	36.0	15.5	17-Jul-00	38.5	28.8
22275	No	BP6772	48.9	55.0	40.7	41.7	23.0	17-Jul-00	38.5	28.8
22209	No	BP6757	45.0	53.3	38.0	36.6	19.0	17-Jul-00	38.5	28.8
25313	Esoph	P7299	43.5	48.5	38.3	36.3	14.6	3-Aug-00	38.5	29.0
22210	Esoph	P7522	47.5	51.4	40.3	39.9	21.1	15-Aug-00	38.5	28.8
22208	Esoph	P7226	46.8	52.0	40.6	39.3	17.4	23-Aug-00	38.5	28.8
22272	Esoph	P7228	47.5	52.0	38.9	39.8	17.6	23-Aug-00	38.5	28.8
22211	Esoph	P7231	44.4	50.0	37.2	36.4	14.4	8-Sep-00	38.6	29.0
25312	Esoph	P7233	47.1	51.1	39.4	39.3	16.2	8-Sep-00	38.6	29.0

Table 2. Satellite transmitter programming configuration. (The year is coded as a 2-digit number. It displays as 1900, but functionally it is year 00, which is equivalent to either 1900 or 2000.)

Quarter-Watt, Microprocessor-controlled Satellite-linked Time-Depth Recorder. **Unit measures depth from 0 to 245 meters with a resolution of 1 meters** **Software version 3.14k. Unit number: *x* ARGOS geolocation id = *y*** **Unit identifier = . Unit started at 08:42:05 on 14/07/00**
Time (GMT) is 08:55:14.51. Date (GMT) is 14 July 1900 Shallowest depth to be considered a "dive" = 2 meters Deepest depth for accumulating surface-timelines (0=dry only) = 1 meters SLTDR uses 1-sec / 1/4-sec wakeups when shallower than 20 / 5 meters Local time [0-23 hours] corresponding to 00h UT (GMT): 22 Transmission intervals (at-sea / on-land) = 00:45.50 / 01:30.50 SLTDR will use on-land interval after 10 consecutive dry transmissions SLTDR will not suspend transmissions during extended "Haul-outs". Transmissions will be duty cycled with 1 day on and 1 day off Daily allowance (1-message transmissions; unused xmits accumulate) = 500 STATUS will be transmitted every 20 messages. Blocks of Time-Lines will be transmitted every 48 messages. Hours when SLTDR transmits: 04,07-09,19-22 Upper limits of maximum-depth histogram bins are: 5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 100, 150, i meters Upper limits of dive-duration histogram bins are: 2, 5, 10, 20, 30, 45, 60, 75, 90, 105, 120, 180, 240, i minutes Upper limits of time-at-depth histogram bins are: 1, 3, 5, 10, 15, 25, 35, 50, 60, 75, 100, 125, 150, i meters Type D to archive depth readings, H to archive histograms: h

Table 3a. Mean dive depths, dive durations, and dive counts during period 0 (21:00 - 03:00 local time) for hooked and control turtles, between 1 October 2000 and 31 October 2000. The sample size (n) for the mean dive count per period is the number of histogram periods for which data were received. Based on the midpoints of the depth bins, the minimum possible mean dive depth is 3.5 meters, and the minimum possible mean duration is 1.0 minute.

* = turtles captured with longline fishing gear.

Turtle Number	**Mean Dive Depth (meters)**	**n**	**Mean Dive Duration (minutes)**	**n**	**Mean Dive Count (# per 6 hr period)**	**n**
22275	4.5	139	5.1	140	12.6	11
22209	6.8	146	3.4	146	24.3	6
25313*	8.8	82	8.7	172	13.7	6
22208*	3.5	401	1.3	401	25.1	16
22272*	6.2	81	28.8	84	8.1	10
22211*	12.1	43	64.6	61	4.3	10
25312*	14.8	30	50.3	56	4.3	7

Table 3b. Mean dive depths, dive durations, and dive counts during period 1 (03:00 - 09:00 local time) for hooked and control turtles, between 1 October 2000 and 31 October 2000. The sample size (n) for the mean dive count per period is the number of histogram periods for which data were received. Based on the midpoints of the depth bins, the minimum possible mean dive depth is 3.5 meters, and the minimum possible mean duration is 1 minute.

* = turtles captured with longline fishing gear.

Turtle Number	Mean Dive Depth (meters)	n	Mean Dive Duration (minutes)	n	Mean Dive Count (# per 6 hr period)	n
22275	19.6	208	8.4	202	14.9	14
22209	20.4	136	7.2	122	13.6	10
25313*	14.3	243	12.6	239	22.1	11
22208*	3.5	285	1.0	285	11.4	25
22272*	5.8	130	18.9	168	10.8	12
22211*	5.5	203	11.7	178	14.5	14
25312*	4.8	423	6.7	334	47.0	9

Table 3c. Mean dive depths, dive durations, and dive counts during period 2 (09:00 – 15:00 local time) for hooked and control turtles, between 1 October 2000 and 31 October 2000. The sample size (n) for the mean dive count per period is the number of histogram periods for which data were received. Based on the midpoints of the depth bins, the minimum possible mean dive depth is 3.5 meters, and the minimum possible mean duration is 1 minute.

* = turtles captured with longline fishing gear.

Turtle Number	Mean Dive Depth (meters)	n	Mean Dive Duration (minutes)	n	Mean Dive Count (# per 6 hr period)	n
22275	28.4	106	8.2	114	7.6	14
22209	10.7	150	3.3	227	18.8	8
25313*	23.3	132	8.3	173	13.2	10
22208*	3.5	830	1.0	830	34.6	24
22272*	5.3	168	13.4	148	12.9	13
22211*	7.0	44	10.0	83	4.0	11
25312*	4.2	228	3.3	396	28.5	8

Table 3d. Mean dive depths, dive durations, and dive counts during period 3 (15:00 – 21:00 local time) for hooked and control turtles, between 1 October 2000 and 31 October 2000. The sample size (n) for the mean dive count per period is the number of histogram periods for which data were received. Based on the midpoints of the depth bins, the minimum possible mean dive depth is 3.5 meters, and the minimum possible mean duration is 1 minute.

* = turtles captured with longline fishing gear.

Turtle Number	Mean Dive Depth (meters)	n	Mean Dive Duration (minutes)	n	Mean Dive Count (# per 6 hr period)	n
22275	22.3	166	9.0	148	11.9	14
22209	16.2	187	5.8	171	20.8	9
25313*	9.9	297	6.6	317	37.1	8
22208*	3.5	221	3.4	221	17.0	13
22272*	4.7	113	18.4	105	11.3	10
22211*	12.0	47	40.0	26	5.2	9
25312*	9.1	88	17.7	93	11.0	8

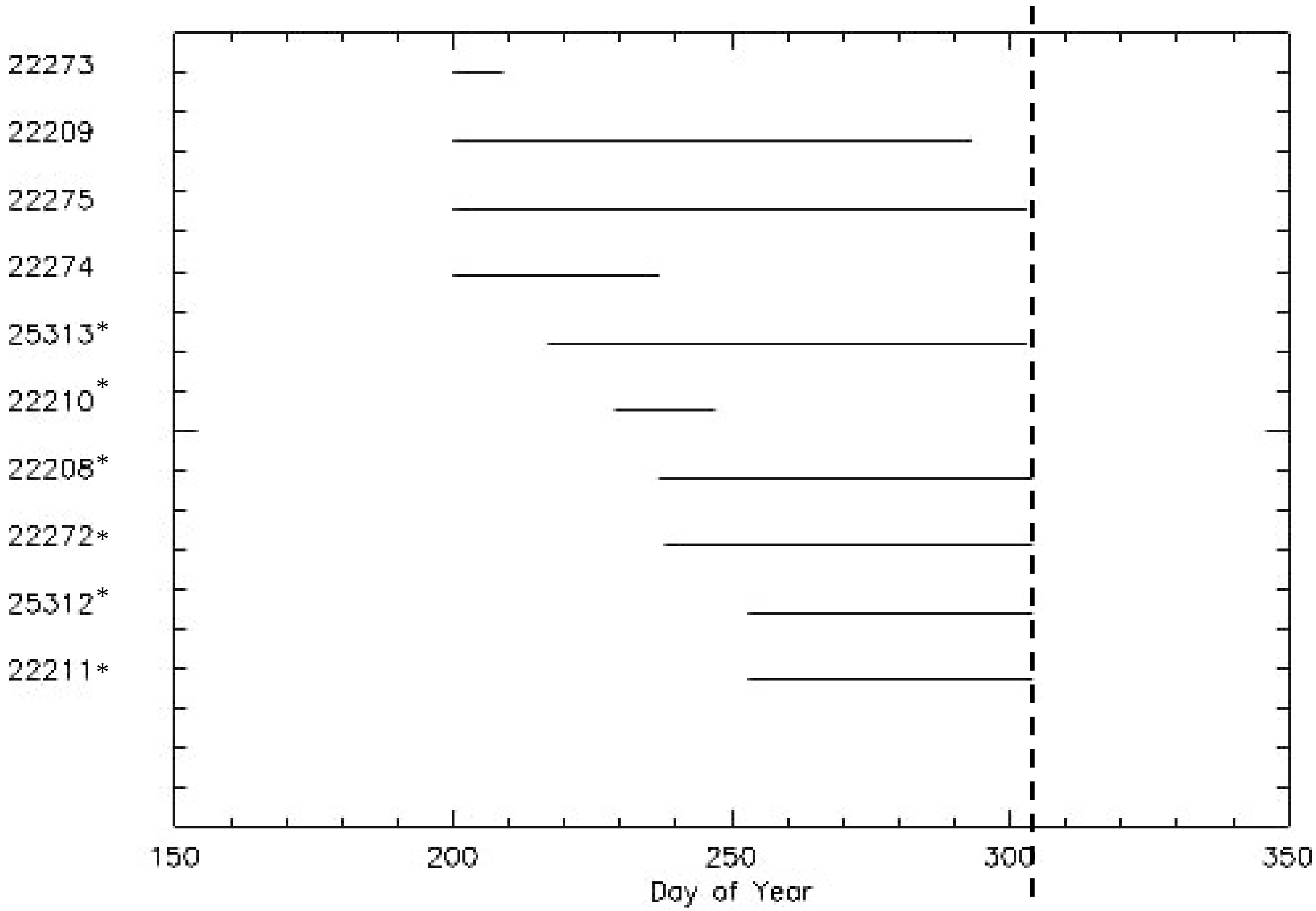

Figure 1. Functional lives of satellite transmitters through 31 October 2000 (day-of-year 305). Asterisks indicate turtles captured with longline fishing gear. The vertical dashed line marks the end of the time period for which we have analyzed the data – the experiment is ongoing.

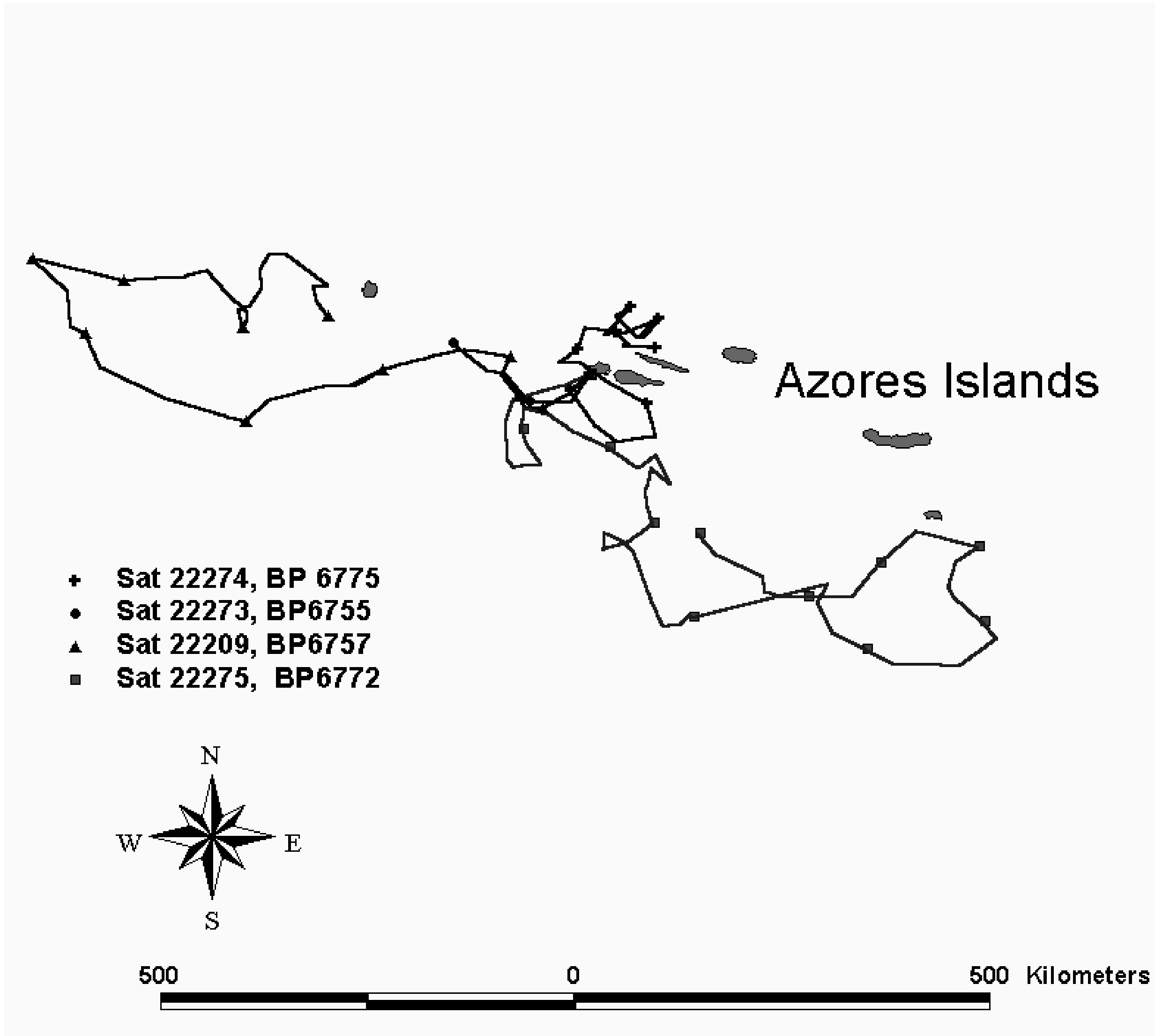

Figure 2a. Movements of four turtles released together on 17 July 2000, through 10 November 2000 or until transmitter failure.

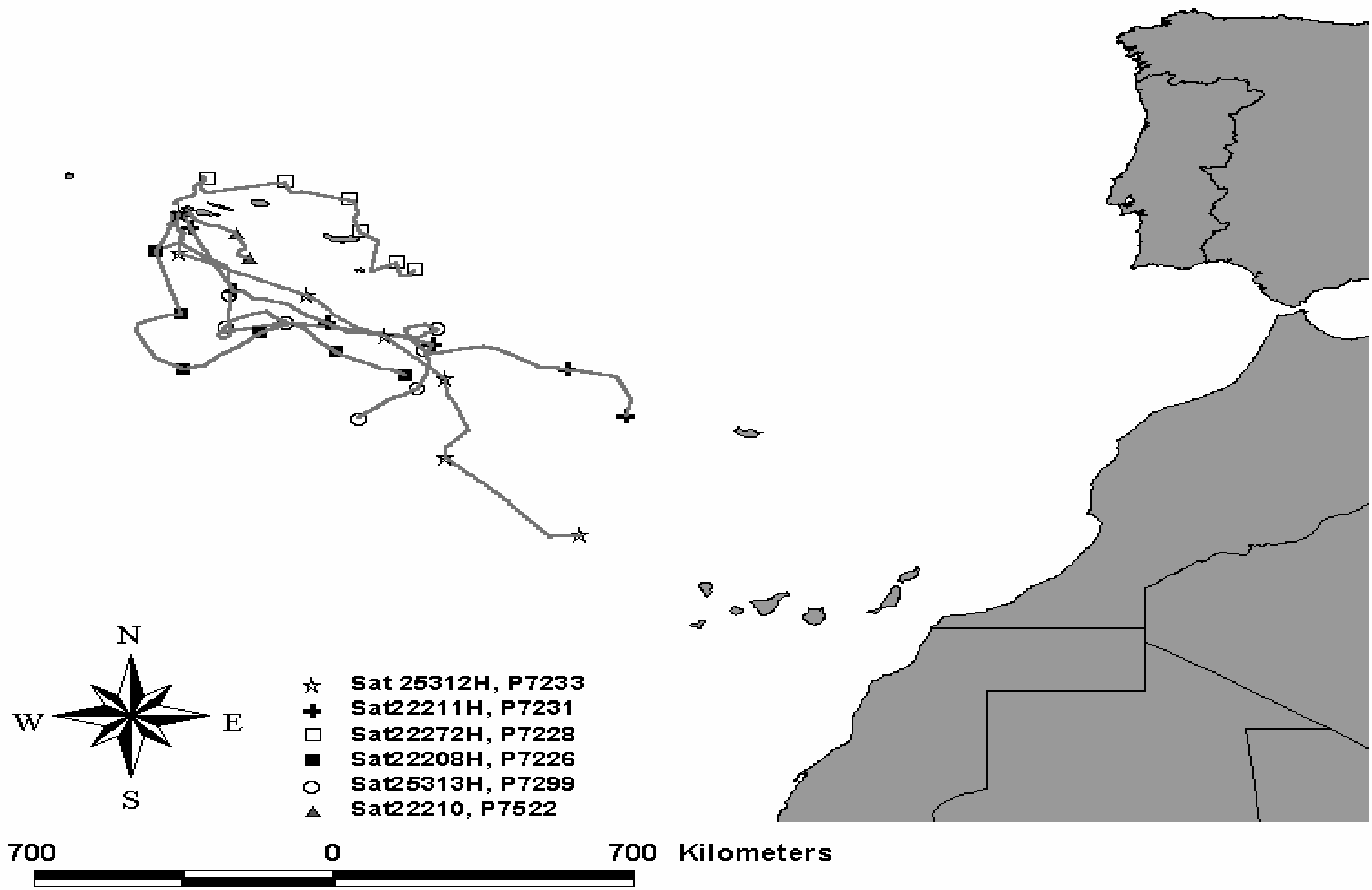

Figure 2b. Movements of 6 turtles hooked in the esophagus from release through 10 November or until transmitter failure.

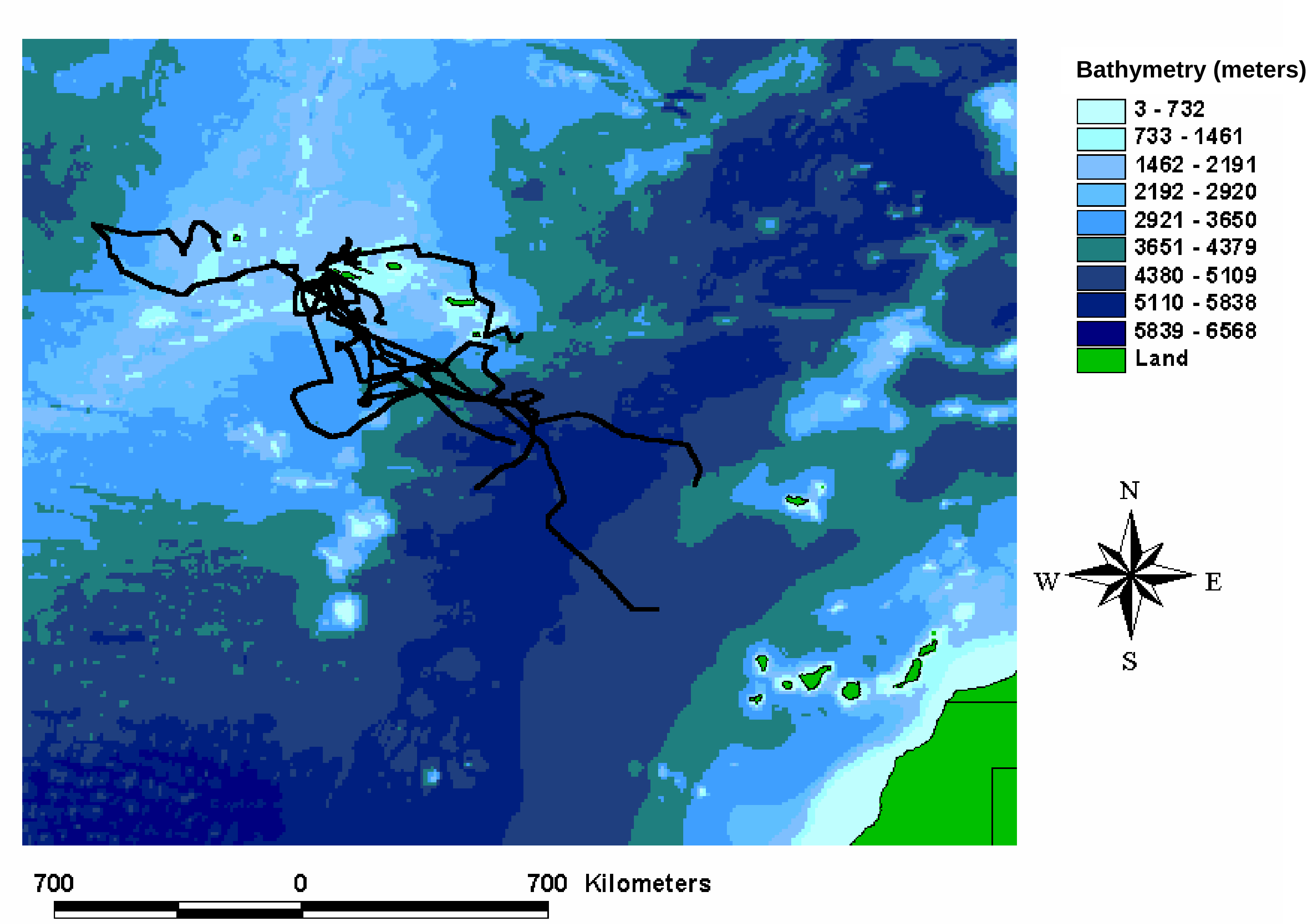

Figure 3. Movements of all turtles with respect to bathymetry.

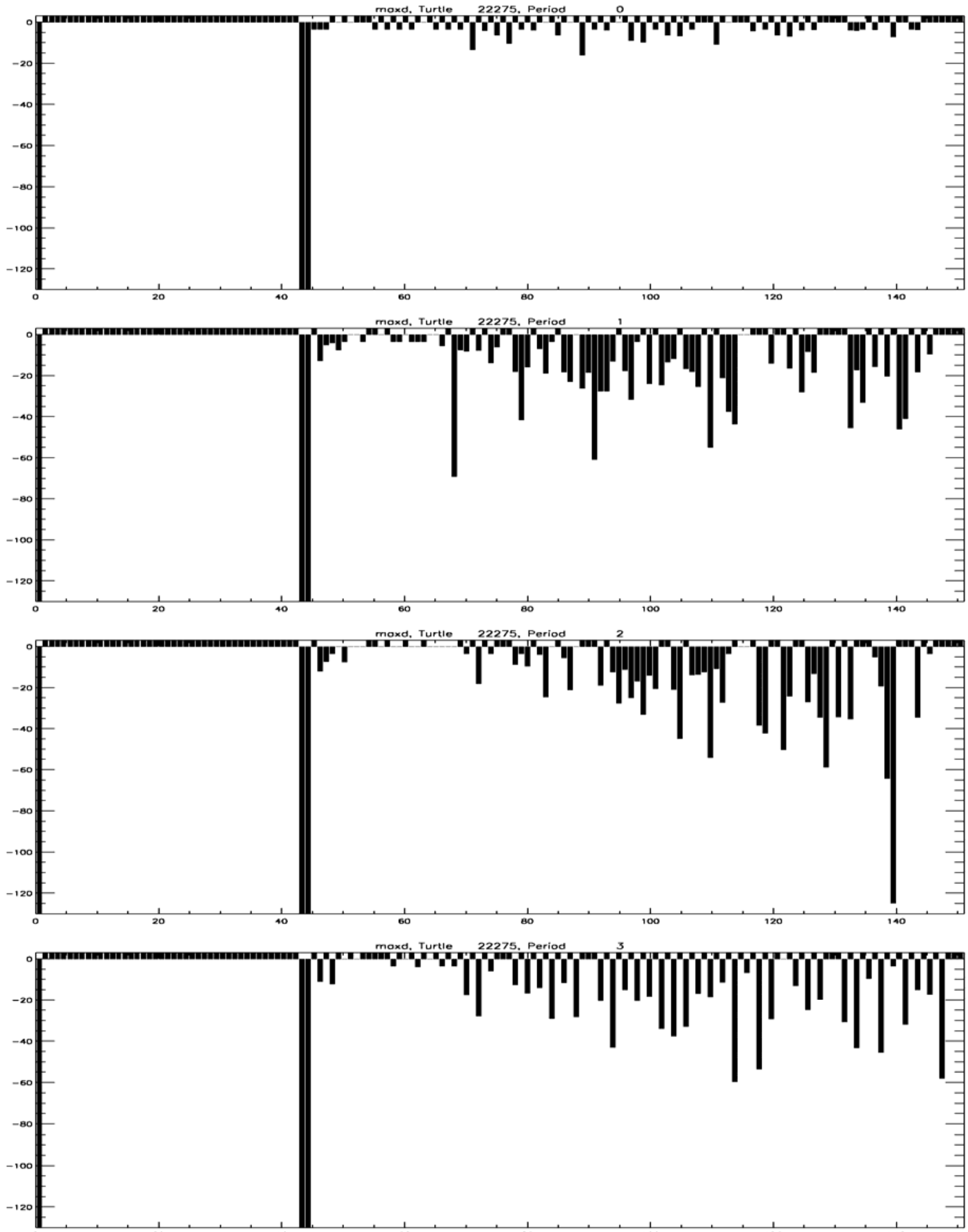

Figure 4a. Daily mean-maximum dive depths (meters) for turtle 22275 (control) during each histogram period, from release on 17 July 2000 through 31 October. The thick vertical bar marks the release date, the x-axis is the number of days since the release of the first turtle of the 2000 field season, and positive depth values indicate missing data.

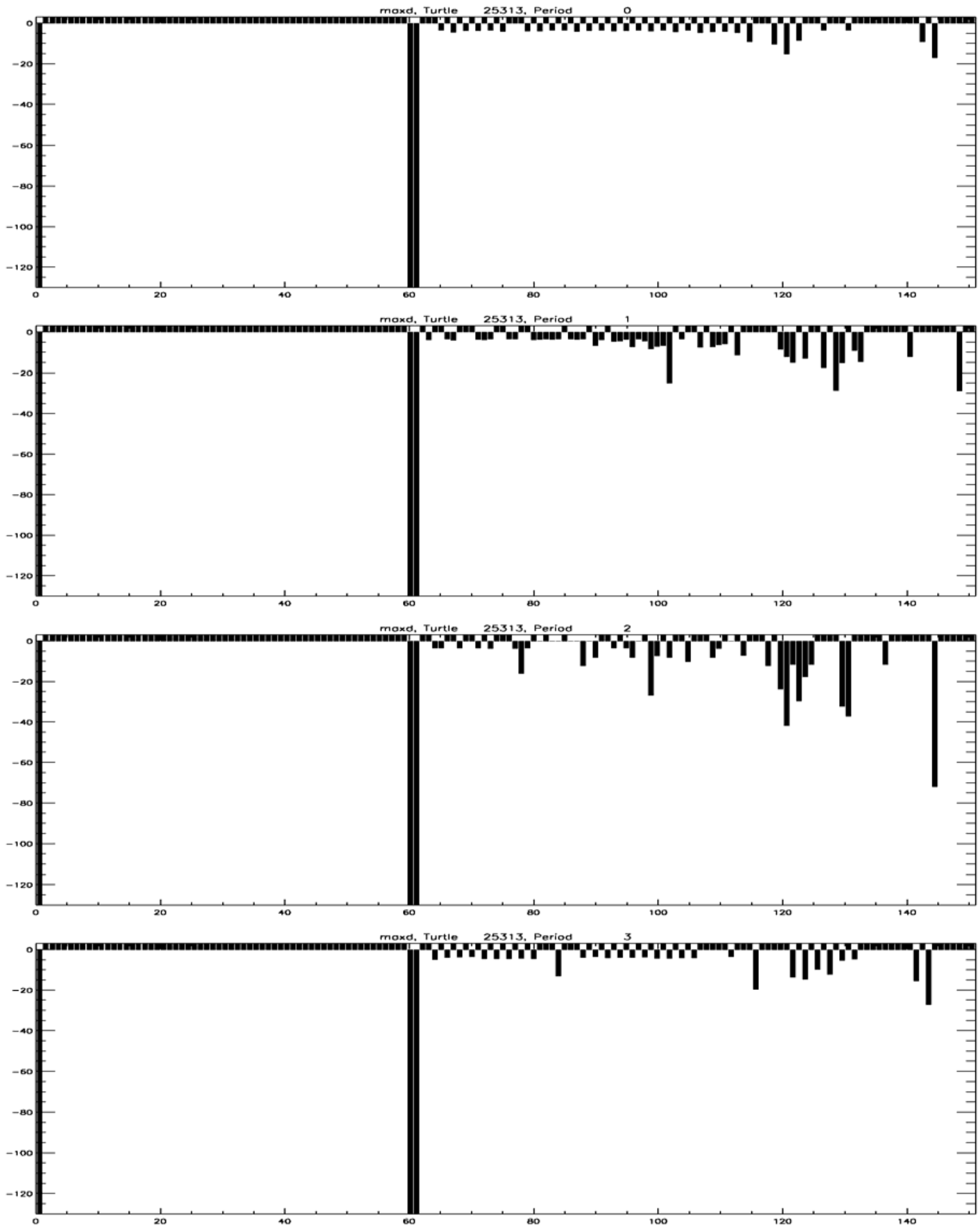

Figure 4b. Daily mean-maximum dive depths (meters) for turtle 25313 (hooked in esophagus) during each histogram period, from release on 3 August 2000 through 31 October. The thick vertical bar marks the release date, the x-axis is the number of days since the release of the first turtle of the 2000 field season, and positive depth values indicate missing data.

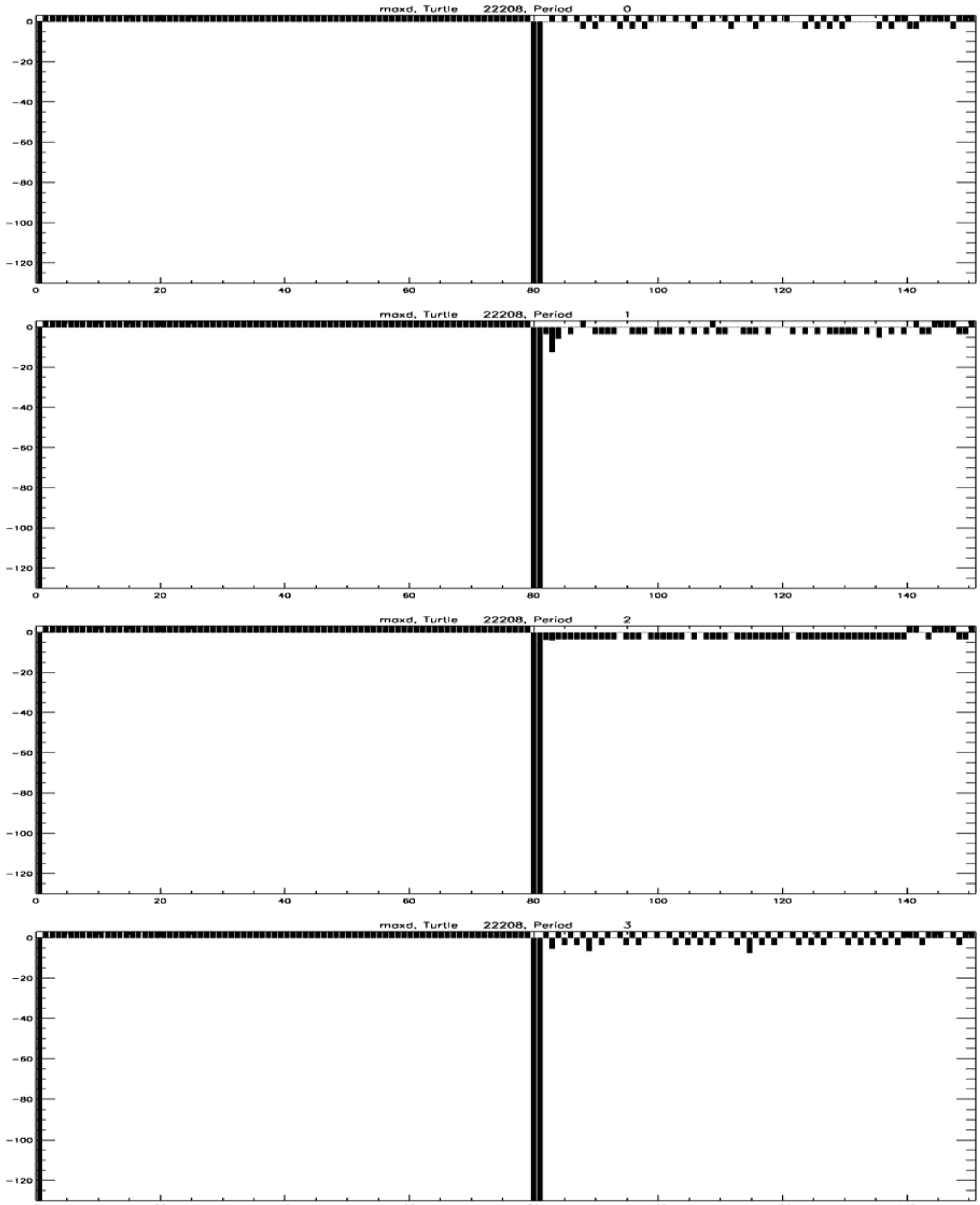

Figure 4c. Daily mean-maximum dive depths (meters) for turtle 22208 (hooked in esophagus and may have subsequently died) during each histogram period, from release on 23 August 2000 through 31 October. The thick vertical bar marks the release date, the x-axis is the number of days since the release of the first turtle of the 2000 field season, and positive depth values indicate missing data.

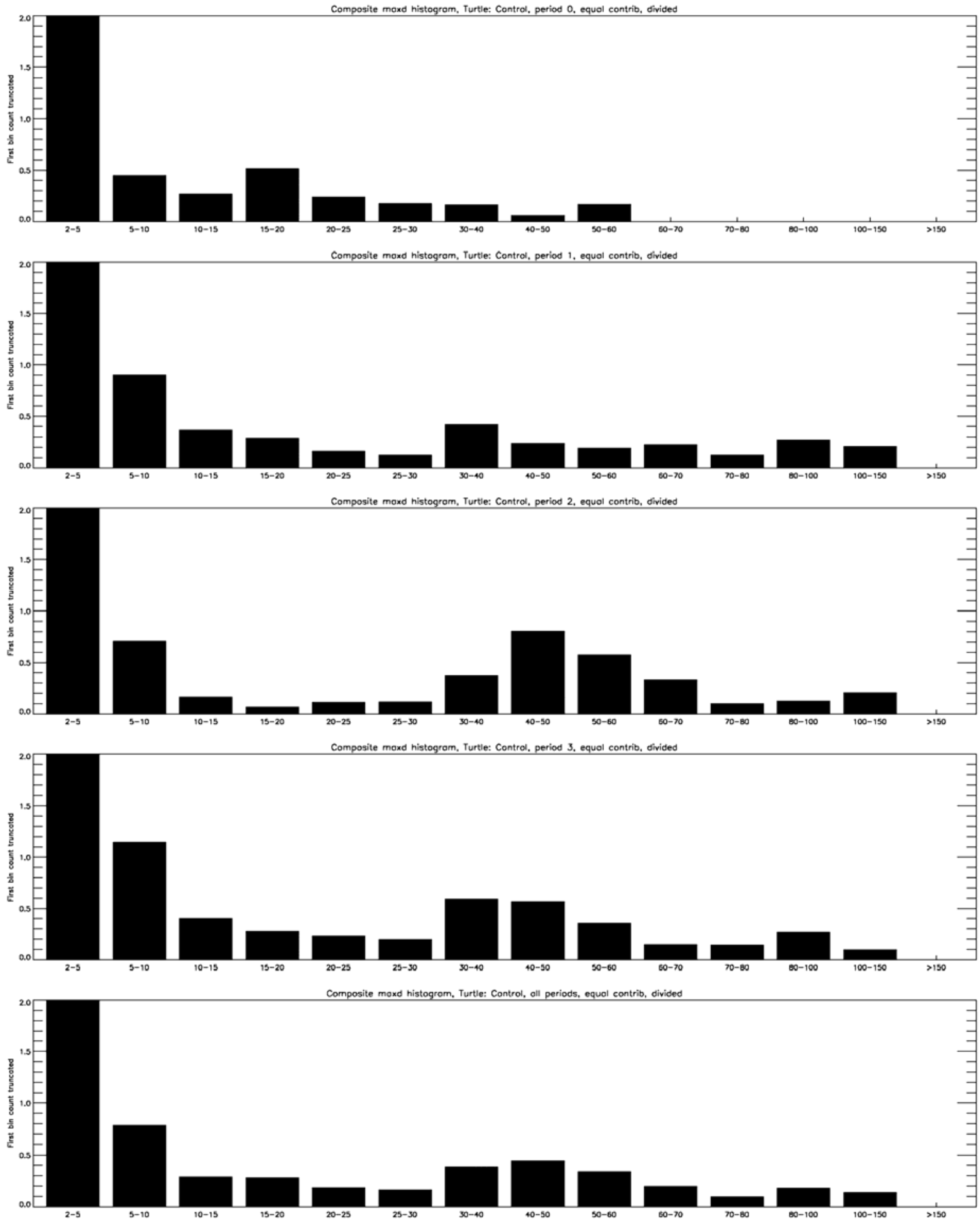

Figure 5a. Composite histogram of maximum dive depths for control turtles from October 1998 and October 2000, from each histogram period and for all periods combined. The control group is composed of 5 turtles from 1998 and 2 turtles from 2000. Depth bins are in meters. The data from each turtle were scaled so that all turtles contributed equally to the final histogram. The first histogram bin has been truncated for display purposes.

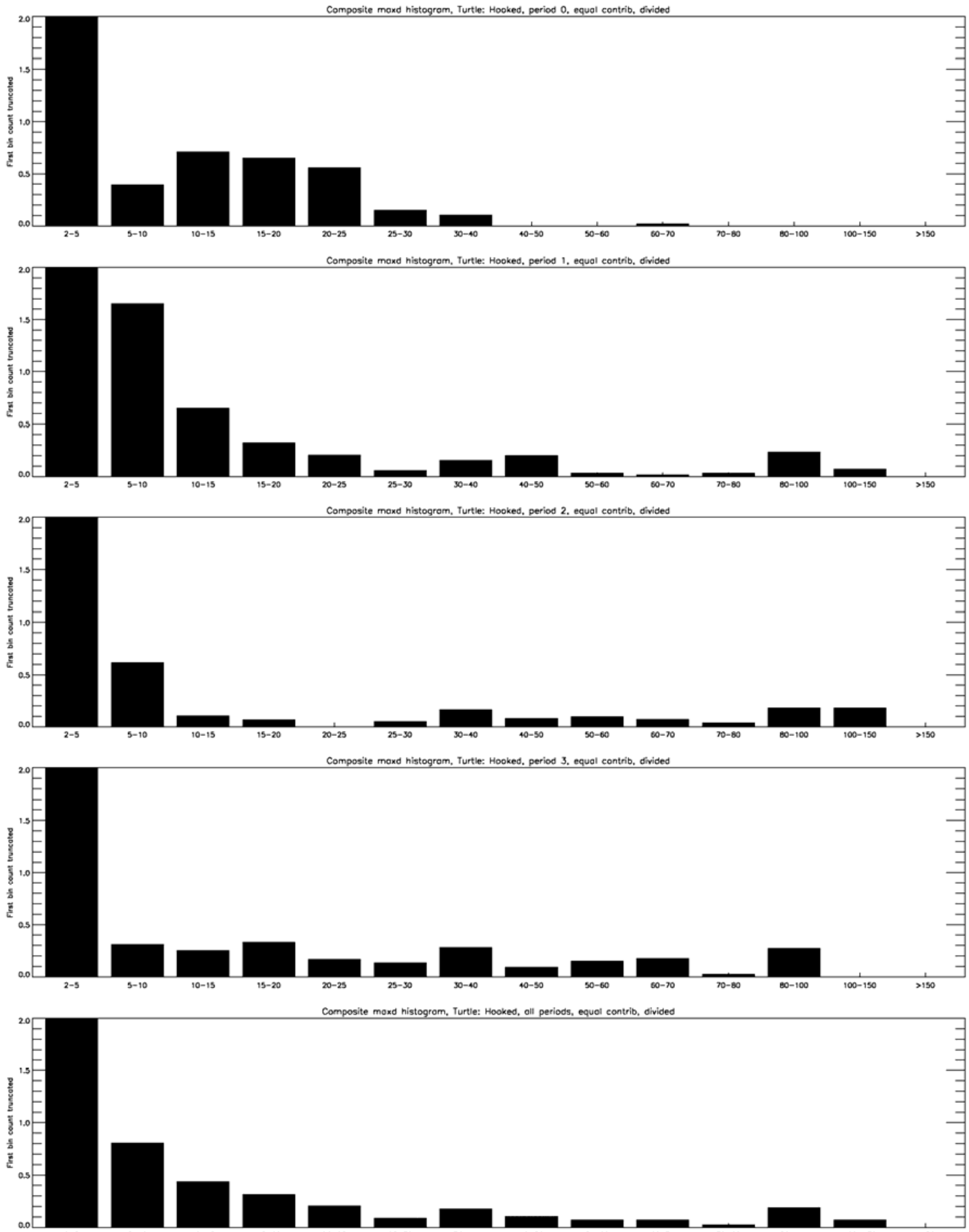

Figure 5b. Composite histogram of maximum dive depths in October for 5 turtles hooked in the esophagus, during each histogram period and with all periods combined. Depth bins are in meters. The data from each turtle were scaled so that all turtles contributed equally to the final histogram. The first histogram bin has been truncated for display purposes.

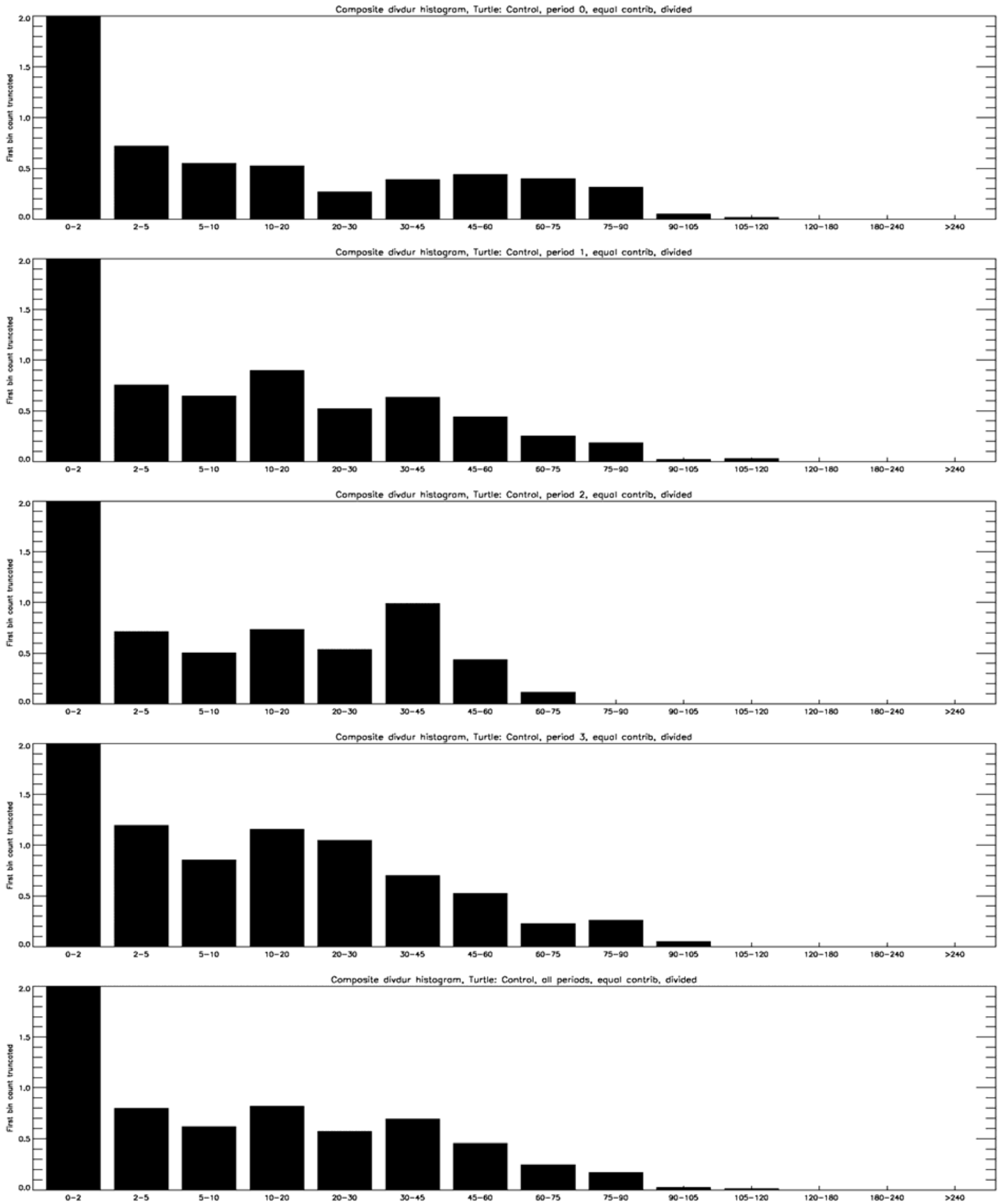

Figure 6a. Composite histogram of dive durations for control turtles from October 1998 and October 2000, from each histogram period and for all periods combined. The control group is composed of 5 turtles from 1998 and 2 turtles from 2000. Dive duration bins are in minutes. The data from each turtle were scaled so that all turtles contributed equally to the final histogram. The first histogram bin has been truncated for display purposes.

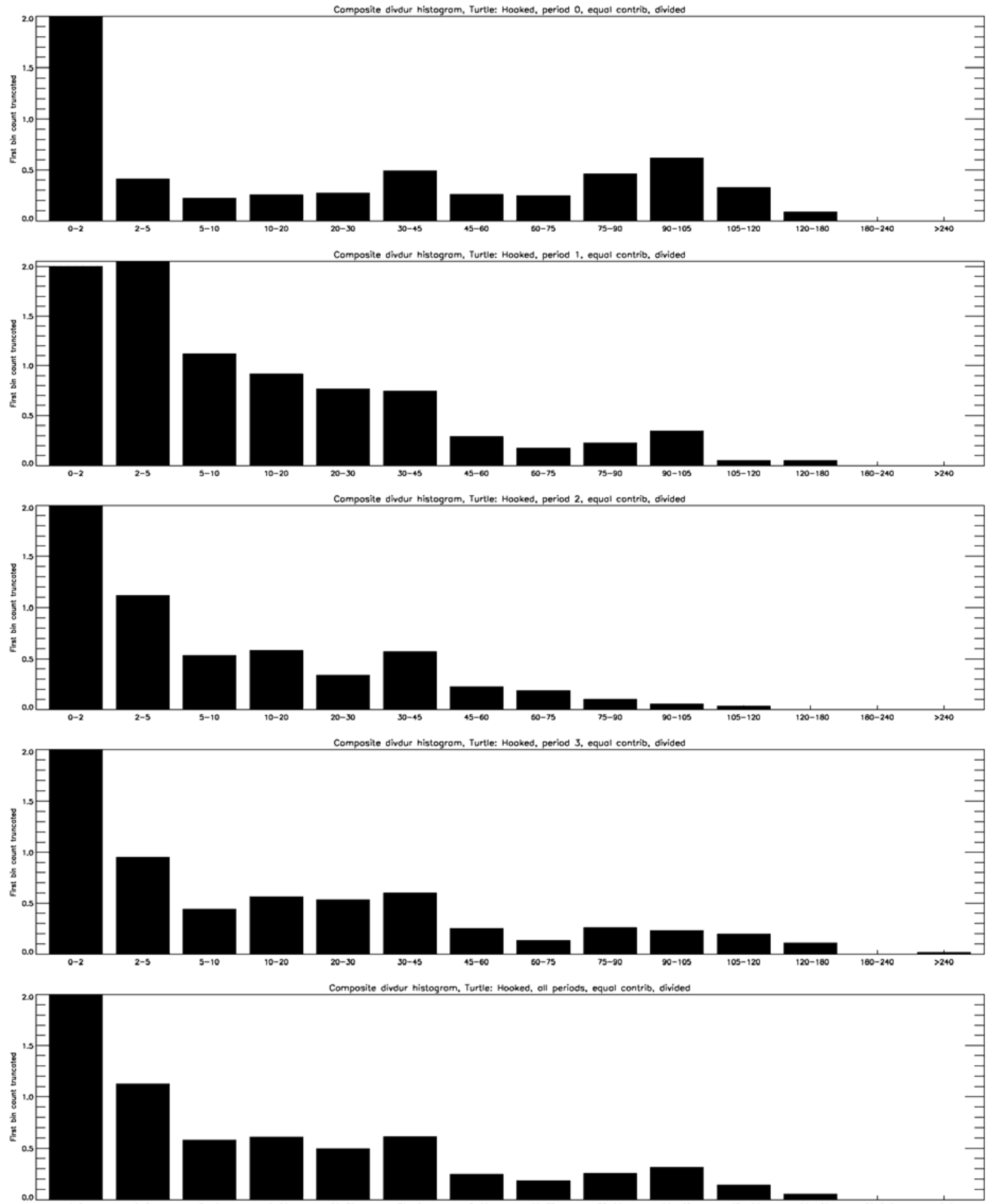

Figure 6b. Composite histogram of dive durations in October 2000 for 5 turtles hooked in the esophagus, during each histogram period and with all periods combined. Dive duration bins are in minutes. The data from each turtle were scaled so that all turtles contributed equally to the final histogram. The first histogram bin has been truncated for display purposes.